RESEARCH HIGHLIGHT

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Validation of an Onsite Wastewater Risk Assessment Model

INTRODUCTION

Failure of onsite wastewater systems (septic systems) can pose significant public health, ecological and financial risks. Such systems are an integral component of wastewater management in rural communities, where development of non-centrally serviced areas is increasing. A risk assessment model can be a valuable tool to help local governments develop rational management plans for decentralized wastewater systems.

There exist a number of risk assessment methodologies. Different approaches are described in the *Onsite Wastewater Treatment Manual* (USEPA, 2002), including the *DRASTIC* model (Aller *et al.*, 1987); the *Risks Assessment System Handbook* (Government of New South Wales, 2001); and the *Guidelines for Assessing the Risk to Groundwater from On-Site Contamination* (British Geological Survey, 2001).

In 2004, as part of an onsite system management plan for the City of Ottawa, a risk assessment model was developed using the same approach as the *DRASTIC* model, which attributes proportional weightings to various risk factors. The model was successfully applied to 19 villages within the City of Ottawa (Kinsley *et al.*, 2004).

MODEL DEVELOPMENT

The model is comprised of factors accounting for contaminant loading, contaminant pathways and age of systems. The model was developed in a GIS format to use readily available information (soils, flood plain, parcel and building mapping, census data, aquifer vulnerability study and local hydro-geological knowledge). Each risk factor is assigned a value of 0–5, with zero representing no risk and five representing a very high risk. Each factor is assigned a corresponding weighting to account for its relative importance in the risk model. The sum of each risk factor multiplied by its weighting determines the risk model value [RISK = $\sum$ (RISK FACTOR X WEIGHTING)].

Table 1 – Risk Assessment Model Factor weighting

Risk Factor	Description	Weighting (% of total)
R_1-A	Soil type – permeable	11.3%
R_1-B	Soil type – impermeable	11.3%
R_2	Depth to groundwater	9.0%
R_3	Aquifer conductivity	3.0%
R_4	Population	15.0%
R_5	Drinking water vulnerability	9.0%
R_6	Lot size	18.8%
R_7	System age	11.3%
R_8	Proximity to surface water	11.3%

MODEL APPLICATION AND SENSITIVITY ANALYSIS

The model was applied to 19 villages within the City of Ottawa, with the scores normalized to a value out of 100. Relative risk varied between 33 and 68, with an average of 51. The model was most sensitive to the factors describing drinking water vulnerability (R_5), population (R_4) and depth to groundwater (R_2). It was least sensitive to the factors describing aquifer conductivity (R_3), lot size (R_6) and proximity to surface water (R_8).

MODEL VALIDATION

Data on system malfunction or failure (from local knowledge, inspection reports and replacement permits), along with groundwater quality data (nitrate, bacteria) and surface water quality data (bacteria, total phosphorus) were used to validate the model's parameters.

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There were two field data collection campaigns during the summers of 2004 and 2005. The researchers also collected historical data from records of replacement systems at the Ottawa Septic System Office.

The first field campaign targeted septic systems on waterfront properties in Tay Valley Township. A certified sewage system inspector made a visual inspection of each leaching bed. Tanks were inspected by opening the inlet manhole and measuring the depth of sludge and scum in the primary chamber of the tank and noting the condition of the inlet baffle. Water samples were collected from the tap (before any treatment device) and from the surface water along the shoreline at the closest distance from the leaching field at each property. Samples were analyzed for *E. coli*, nitrate, chloride and total phosphorus following Standard Methods (APHA/AWWA/WEF, 1998).

The second field inspection was conducted in eastern Ontario as part of a parallel study on the impact of water softener discharge on septic tanks (Kinsley *et al.* 2006). René Goulet of Goulet Septic Tank Pumping collected the field data, with researchers from the Ontario Rural Wastewater Centre.

A survey form was filled out with each homeowner to gather information on each system, including: tank age, date of last pump-out, number of occupants and bedrooms, type of septic system, soil type and any history of bed failure or water quality problems. The size, material and condition of each tank were documented; the sludge and scum depth measured; and the state of the leaching bed evaluated.

The third source of data is the historical records of replacement systems at the Ottawa Septic System Office. Data from construction-permit files for replacement systems installed within the past eight years were collected. Information in the database includes system location, type of onsite technology that failed, soil type, depth to high groundwater and system age. The soil and high groundwater level data were taken from the test pit data reported in the files. The system age was sometimes in the file, but often the age of the building was used to represent the system age.

DATA ANALYSIS

Field data collection campaign no. 1

Results from this field study found no correlations between system performance and ground or surface water quality. This suggests that it is not appropriate to use water quality data as a general indicator of onsite system performance. However, the use of groundwater quality data (nitrate, *E. coli* and perhaps chloride) and surface water quality data (total phosphorus and *E. coli*) can provide important information to identify impacted areas and prioritize re-inspection programs.

Field data collection campaign no. 2

Of 75 systems evaluated, 12 were experiencing hydraulic failure; where failure is defined as surface breakout (two systems) or water level in the tank higher than the outlet (10 systems). Nine of the 12 systems were installed in clay soils, representing 41 per cent of the systems installed in clay soils, compared with just six per cent failure of systems in other soil types. The failed systems ranged in age from 10–40 years, with an average of 28 years compared with an average age of 20 years for functioning systems. These results suggest that both soil type (clay) and system age (>20 years) are strong indicators of hydraulic failure.

Historical records of the Ottawa Septic System Office indicate that the proportion of systems failing within the first 10 years of operation is much lower than the proportion of housing stock, while the proportion of systems failing after 30 years of operation is much higher than the proportion of housing stock. The relative risk of failure increases 12-fold for systems greater than 30 years old compared to systems less than 10 years old. Poor (impermeable) soils increase risk of failure by 1.5–2.3 times.

REVISED RISK ASSESSMENT MODEL

Based on analysis of this data, the risk assessment model was simplified and revised to reflect a better understanding of the impact of system age and soil type on system failure. The revised model has two components:

1. A **community context**, which provides the rationale and context for an onsite wastewater system management program.
2. A revised **onsite wastewater risk assessment model** consisting of six factors:
   - system age
   - soil
   - lot size
   - depth to HGWT (high groundwater table)
   - aquifer conductivity
   - proximity to surface water

COMMUNITY CONTEXT

Water use

The uses of a water resource should be considered when defining the scope of an onsite, wastewater management program. Typical water uses that could be influenced by onsite wastewater discharges include drinking water wells in a shallow or unconfined aquifer or surface water recreational uses including swimming, boating or sport fishing. Aquaculture is also an important water use in coastal areas.

Water quality

Water quality indicators of both groundwater and surface water can be used to justify or monitor the success of an onsite wastewater management program. Typical indicators for groundwater quality are nitrate and *E. coli*, while typical indicators of surface water quality are total phosphorus and *E. coli*. Suggested threshold limits that can be used to increase the scope or importance of a management plan could include:

- 0 CFU/100mL *E. coli* for groundwater (Universal Drinking Water Standard)
- 100 CFU/100mL *E. coli* for surface water (Ontario PWQO – Bathing)
- 0.01 mg/L TP for surface water (50 per cent of Ontario PWQO to avoid eutrophication)
- 2.5 mg/L nitrate (NO_3) (25 per cent of Ontario Drinking Water Standard)

Other sources of water contamination

Onsite wastewater systems are typically not the sole source of water quality impairment; therefore other non-point sources, including agricultural runoff, and point sources, such as sewage outfall, should be incorporated into any strategy aimed at improving water quality.

ONSITE WASTEWATER RISK ASSESSMENT MODEL

The onsite wastewater risk assessment model uses the same approach as the *DRASTIC* model (Aller *et al.*, 1987), which attributes proportional weightings to a various risk factors.

The model is comprised of a series of factors accounting for contaminant loading, contaminant pathways, and age of systems. Each risk factor is assigned a value of 0–5, with zero representing no risk and five representing a high risk. Each factor is assigned a corresponding weighting to account for its relative importance in the risk model. Table 2 describes the weightings. The sum of each risk factor multiplied by its weighting determines the risk model value [RISK = ∑ (RISK FACTOR X WEIGHTING)].

Table 2 – Onsite wastewater risk assessment model factor weighting

Risk Factor	Description	Weighting (% of total)
R_1	System age	30%
R_2	Soil	15%
R_3	Lot size	15%
R_4	Depth to high ground water table	15%
R_5	Aquifer conductivity	5%
R_6	Proximity to surface water	20%

The model can be applied by area (subdivision, village, lakefront, etc.) or by individual lot. A description of each risk factor follows.

RISK FACTORS

Table 3 – R_1 – System age

System age (years)	Risk rating
0–9	0.4
10–29	2.1
>30	5

R_1 — System Age: Relative risk of failure due to system age has been shown to increase from 1 to 5 to 12 times as the age of the system increases from 1–9 years to 10–29 years to 30 years and older. The building age can be used to represent the age of the onsite system when onsite system records are incomplete.

Table 4 – R_2 – Soil type

Estimated soil hydraulic conductivity, K (cm/s)	R_2 — Soil impermeability
$\leq 10^{-6}$	5
10^{-5}	3
10^{-4}	0.5
10^{-3}	0
$\geq 10^{-2}$	0

R_2 — Soil Type: The soil type is based upon surficial geology mapping. The type of soil reflects the hydraulic conductivity of systems built using in situ soils as well as soils beneath systems constructed with imported sand. The various soil types were classified by hydraulic conductivity (K) as described in Table 4. The soil type factor reflects the increased risk of system clogging and surface break out of effluent (low K values). An area-weighted average can be calculated, or soil data from septic system records can be used for individual lots.

Table 5 – R_3 – Lot size

Lot size	Risk rating
0–0.1 ha (0–0.25 acres)	5
0.1–0.2 ha (0.25–0.49 acres)	4
0.2–0.4 ha (0.49–0.99 acres	3
>0.4 ha (0.99 acres)	1

R_3 — Lot Size: Lot size provides an indirect measure or wastewater loading to the groundwater. As well, small lots often do not meet regulatory separation distances and may pose a risk to drinking water safety and quality. The highest risk is assigned to lots of less than 0.1 ha (0.25 acres), while the lowest risk is assigned to lots of greater than 0.4 ha (1 acre). Table 5 describes the risk ratings for lot size.

Table 6 – R_1 – Depth to high groundwater table

Estimated high seasonal water table depth	Risk rating
> 5 m (16.4 ft.)	1
1–5 m (3.2–16.4 ft.)	3
< 1 m (3.2 ft.)	5

R_1 — Depth to high groundwater table: The depth of the seasonal high water table is estimated for an area based on a subjective assessment by a hydrogeologist with local knowledge. A seasonal high water table at a depth of greater than 5 m (16.4 ft.) is considered to be low risk while a seasonal water table of less than 1 m (3.2 ft.) is considered to be high risk, as described in Table 6. Alternately, data from septic system inspection files can be used to provide a lot specific high water table value, although this information is often not available.

R_2 — Aquifer Conductivity: This factor can be taken directly from an aquifer vulnerability study for the area of interest. These studies have been conducted for many municipalities. Aquifer conductivity refers to the hydraulic conductivity of the groundwater aquifer underlying the study area. Higher hydraulic conductivity increases the potential for pollution, as it facilitates the migration of contaminants through the aquifer.

Table 7 – R_3 – Proximity to surface water

Part of lot within the floodplain	Risk rating
Yes	5
No	0

R_3 — Proximity to Surface Water: The 100-year flood plain boundary is used to determine lots that are in close proximity to a water body. Each lot partially to fully within the floodplain is considered high risk. All other lots are considered no risk. Table 7 describes the risk ratings for proximity to surface water.

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